Debris characterization diagnostic for the NIF

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(Presented on 19 June 2000)

Generation of debris from targets and by x-ray ablation of surrounding materials will be a matter of concern for experimenters and National Ignition Facility (NIF) operations. Target chamber and final optics protection, for example debris shield damage, drive the interest for NIF operations. Experimenters are primarily concerned with diagnostic survivability, separation of mechanical versus radiation induced test object response in the case of effects tests, and radiation transport through the debris field when the net radiation output is used to benchmark computer codes. In addition, radiochemical analysis of activated capsule debris during ignition shots can provide a measure of the ablator $\langle \rho r \rangle$. Conceptual design of the Debris Monitor and Rad-Chem Station, one of the NIF core diagnostics, is presented. Methods of debris collection, particle size and mass analysis, impulse measurement, and radiochemical analysis are given. A description of recent experiments involving debris collection and impulse measurement on the OMEGA and Pharos lasers is also provided. © *2001 American Institute of Physics.* [DOI: 10.1063/1.1310587]

INTRODUCTION

Debris generated from National Ignition Facility (NIF) experiments may have contributions from target and support materials, shields, and diagnostic pinholes with a wide variety of compositions. This debris is important for several reasons: target chamber and final optics protection,[1] interpretation of radiation effects test results,[2] diagnostic survivability, and computer simulations of net radiation output. In addition, radiochemical analysis of debris collected from ignition shots is diagnostic of capsule performance. The Debris Monitor and Rad-Chem Station address these interests by collecting debris for characterization of mass and particle size distribution, measurement of debris impulse, and radiochemical analysis of activated debris. The diagnostic is composed of a suite of collectors and sensors that may be placed at various locations on the target chamber to cover multiple lines of sight. Capabilities of the diagnostic will be fielded in stages, the first being mass, particle size distribution, and impulse measurement. Detailed techniques for performing radiochemical analysis of collected samples remain to be developed as specific experiments are defined. As a result the capability is being protected as ''not to preclude,'' meaning that implementation of debris collection will not unreasonably constrain the ability to perform radiochemical analysis on collected samples. This article describes the conceptual design of the Debris Monitor and Rad-Chem Station and recent experimental experience at the University of Rochester OMEGA and the Naval Research Laboratory (NRL) Pharos laser facilities with debris collection and impulse sensors.

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DEBRIS MASS AND PARTICLE SIZE

Debris mass and particle size distribution analysis will be accomplished by collection of debris onto a glass slide or silicon wafer housed in a clean box, followed by optical inspection. The clean box is loaded in a class 100 clean room, then placed on a diagnostic instrument manipulator (DIM)[3] cart. The DIM allows insertion of diagnostics into the NIF target chamber and the cart is a removable portion for offline diagnostic loading, alignment, etc. Figure 1 shows a schematic of the clean box with two collectors. Once the chamber/DIM is under vacuum the clean box is opened remotely. It is kept open for one or more shots, then remotely

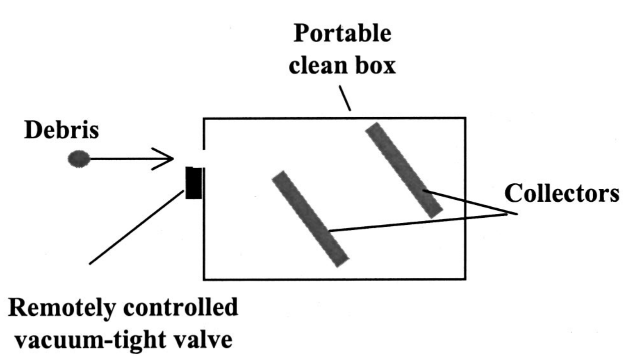

FIG. 1. Schematic of clean box and debris collection surfaces. The box is housed in a DIM and opened remotely before shot.

TABLE I. Specifications for debris mass and particle size analysis.

Debris size distribution	1–500 μm
Mass limit	1 μg
Temporal response	None
Collector area	>1 cm^2

closed, and removed from the DIM cart. The box is then transported to the clean room, placed on a microscope, and automated counting of sizes and shapes is performed. The slide is returned for further analysis as needed. Specifications for the debris mass and particle size analysis are presented in Table I.

Another collection mechanism that has been recently investigated is medium- and high-density silicon aerogel obtained from NASA.[4] This approach has the advantage of preserving the particle track so that an analysis of its velocity can be performed in addition to mass and size. We have fielded a pair of these collectors on OMEGA shots. Figure 2 is a schematic of the experimental setup and Fig. 3 shows particulate that was collected during these shots. The exposure area of each aerogel was 5 cm^2, with nominal thickness of 3 cm. Postshot inspection of the surfaces of the aerogels indicate the importance of maintaining clean conditions for quantitative measurements when low-velocity debris is of interest. Analysis of the particulate tracks and composition is currently being performed by NASA.

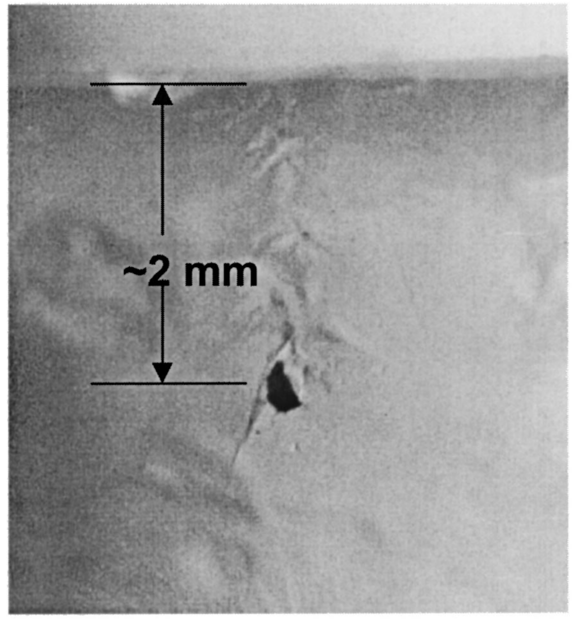

FIG. 3. Aerogel debris collector showing particle and associated track. This sample was recently collected from a Au hohlraum target shot on the OMEGA laser.

DEBRIS IMPULSE

Passive impulse gauges fielded on the Nova laser demonstrated the capability of making this type of measurement using a simple technique, free from electrical noise issues often associated with a high-power laser environment.[5] On NIF however, automation of diagnostics is highly desirable and we are focusing our efforts on active methods using a variety of sensors, allowing a large dynamic range to be covered. In general, the sensor is imbedded into a solid cylinder of material with a well known equation of state (e.g., aluminum). The cylinder is placed into the NIF via a DIM cart. Pressure waves in the cylinder generated by impacting debris are measured by the sensor and the impulse of the debris is backed out from the data utilizing the known equation of state. The diagnostic is remotely controlled by computer and the pressure signal is recorded on a scope.

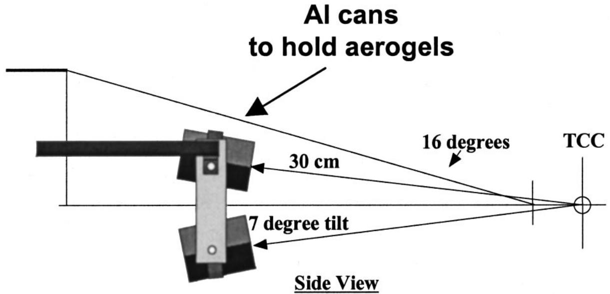

FIG. 2. Experimental setup for the aerogel collectors at the OMEGA laser facility.

Three types of sensors are currently under evaluation, étalon probes,[6] ruby sensors, and polyvinylidene fluoride (PVDF) gauges.[7] The étalon probes consist of microchip interferometers attached to 50 μm core optical fibers and have a sensitivity range of ~1–1000 bar. Ruby sensors (custom mated to fiber optics by NRL) are sensitive to higher pressures, covering ~2–100 kbar. The piezoelectric PVDF gauges compliment the étalon probes and ruby sensors, with operational pressure range of ~0.5–500 bar. Table II contains the specifications for the debris impulse measurement.

Impulse measurement experiments have recently been carried out on the OMEGA and Pharos lasers. On OMEGA, a PVDF sensor was fielded on Au hohlraum shots and demonstrated operation in a laser environment with very low noise (<1 mV). A schematic of the PVDF sensor is shown in Fig. 4. On the Pharos laser, an experiment was performed that compared an étalon gauge with an electrical carbon gauge on the same shot. The shock was generated by focusing a laser beam into water, so that the electrical environment was that of a laser. Figure 5 shows the results. The first pulse on the étalon trace is laser light at $t=0$, the second pulse is the pressure response, and the third pulse is a reflection from nearby material. The carbon trace shows a small pressure pulse and a much larger set of signals arising from electrical noise.

RADIOCHEMISTRY

The $(n,2n)$ production of ^{62}Cu and ^{64}Cu from naturally occurring ^{63}Cu and ^{65}Cu in the Cu-doped Be ablator is pro-

TABLE II. Specifications for debris impulse measurement.

Pressure range	1 bar–100 kbar
Gauge diameter	<500 μm–2 cm
Temporal response	<15 ns

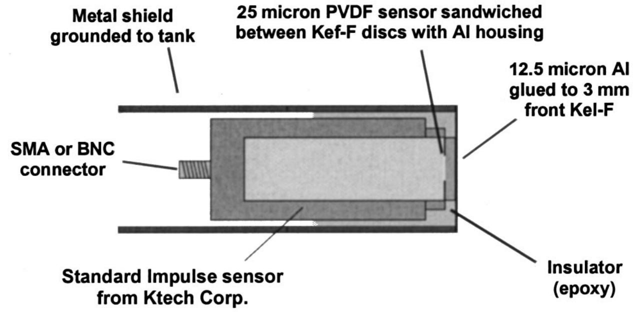

FIG. 4. Schematic of the PVDF impulse gauge recently fielded on OMEGA.

portional to the ablator $\langle \rho r \rangle$ and neutron yield.[8] The measurement would be performed by capturing a fraction of the capsule explosion debris and counting the decay of activated copper, then using a chemical analysis of Cu or Be in the sample to determine the capsule fraction obtained. The collected sample would be counted quickly because of the relatively short half lives of ^{62}Cu and ^{64}Cu (9.7 min and 12.9 h, respectively).

Both ^{62}Cu and ^{64}Cu decay by positron emission, accompanied by annihilation radiation (511 keV), and each emits discrete γ rays that may be used for identification and quantification. Coincidence counting of the annihilation radiation covering a period of a few half lives is an established method for measuring ^{62}Cu and ^{64}Cu activation.[9] This method has the advantage of being most sensitive to lower yields, but lacks the unambiguous isotope identification that comes from measuring discrete γ rays, which may be performed with a high-purity intrinsic Ge detector. Recent experiments on the Petawatt laser at Livermore have demonstrated the feasibility of measuring ^{62}Cu and ^{64}Cu directly via the 1173 and 1345 keV γ rays, respectively, at levels well below those of nominal full yield on NIF.[10] Yields as low as $1E-6$ of nominal full yield will produce enough activity for ablator $\langle \rho r \rangle$ determination using the coincidence counting technique. We also anticipate that radiochemical analysis of a variety of activation products will be useful in diagnosing experiments

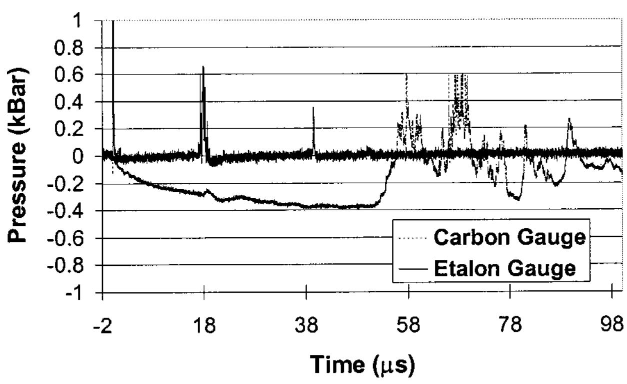

FIG. 5. Étalon probe results vs carbon gauge for a laser-induced shock in water at the Pharos laser facility at the Naval Research Laboratory.

TABLE III. Specifications for radiochemical analysis.

Geometric collection efficiency	$>1E-6$
Maximum removal time	2–20 min
Detector resolution	<2.5 keV @ 1173 KeV
MDL (atoms)	
^{62}Cu	$1E4$
^{63}Cu	$1.3E11$
^{64}Cu	$1E5$
^{65}Cu	$6E10$
^{9}Be	$\sim 1E11$
^{10}Be	$\sim 1E11$
Temporal response	None

well before ignition is achieved on NIF. Table III presents specifications for the Rad-Chem Station.

SUMMARY

The Debris Monitor and Rad-Chem Station is being developed for the NIF as one of the core diagnostics. Methods of debris collection proposed and under current investigation include glass slides, silicon wafers, and silicon aerogels. Impulse sensors to cover a wide dynamic range are being evaluated and include étalon probes, ruby sensors, and PVDF gauges. Radiochemical analysis of activated debris will enable a measurement of the ablator $\langle \rho r \rangle$ for ignition shots as well as providing a general capability to diagnose experiments that produce activation products. Offline development and testing on the OMEGA and Pharos lasers will continue so that the diagnostic may be completed and operational for first use on NIF in 2004.

ACKNOWLEDGMENTS

The authors would like to thank the OMEGA operations staff, and in particular Jack Armstrong, for assistance in fielding the debris collectors and impulse gauges. This work was carried out under the auspices of the United States Department of Energy by the University of California Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48 and is supported in part by the United States Defense Threat Reduction Agency under Contract No. IACRO 00-3003, Work Unit 6172. The NRL is supported by the United States Defense Threat Reduction Agency under a separate contract.

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